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14. ABSTRACT

LanDPro goals included enhancing and integrating soil, geomorphic, and hydrogeologic projects that DRI conducts for DoD and aided in improving the robustness and universality of existing tools in support of natural and cultural resources management on DoD installations in the southwest United States. LanDPro activities have included system-wide installation visits, briefings, geoarchaeology workshop, presentations at national and international scientific meetings, and developing cooperative and collaborative research efforts in support of natural and cultural

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Report Title

LanDPro: Landscape Dynamics Program
Final Report: Scientific progress and accomplishments

ABSTRACT

LanDPro goals included enhancing and integrating soil, geomorphic, and hydrogeologic projects that DRI conducts for DoD and aided in improving the robustness and universality of existing tools in support of natural and cultural resources management on DoD installations in the southwest United States. LanDPro activities have included system-wide installation visits, briefings, geoarchaeology workshop, presentations at national and international scientific meetings, and developing cooperative and collaborative research efforts in support of natural and cultural resources management at home and abroad. A geoarchaeology workshop defined areas of mutually beneficial geomorphic and archaeological research. A geomorphic-based archeological predictive model was developed and applied by integrating soils, geomorphology, landscape history, geology, and cultural resources database into a GIS platform. Subsurface stratigraphic models were developed by integrating borehole cores, trenches, GPR, soils stratigraphy, and geomorphic mapping for assessment of buried archaeological site potential. LanDPro efforts contributed to our understanding of, and ability to distinguish naturally occurring features in the landscapefrom anthropogenic features.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

<u>Received</u>   <u>Paper</u>

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

<u>Received</u>   <u>Paper</u>

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Bullard, T.F. and McDonald, E.V., 2011, Soil-geomorphic based archaeological predictive modeling in management of cultural resources on military training and testing installations. in, T.F. Bullard and E.V. McDonald, (eds), Desert Warfare -- Past Lessons, Future Challenges. 9th International Conference on Military Geology and Geography, p. 28-29.

McDonald, E., 2011, Desert terrain, mule meat, and bloody lances: Kearny's "Army of the West" march across California during the mexican-American War. in, T.F. Bullard and E.V. McDonald, (eds), Desert Warfare -- Past Lessons, Future Challenges. 9th International Conference on Military Geology and Geography, p. 78-79.

McDonald, E., Bacon, S., Schumer, R., Jenkins, S., and Caldwell, T., 2011, The question of the origin of cleared circles as cultural resource features: weary humans or energetic rodents? in, T.F. Bullard and E.V. McDonald, (eds), Desert Warfare -- Past Lessons, Future Challenges. 9th International Conference on Military Geology and Geography, p. 80-81.

Number of Presentations: 3.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

<u>Received</u>   <u>Paper</u>

09/18/2012   1.00   Thomas Bullard, Eric McDonald. 9th International Conference on Military Geology - Desert Warfare: Past Lessons, Future Challenges,
9th International Conference on Military Geology. 2011/06/20 03:00:00, . : ,

09/18/2012   4.00   Thomas F. Bullard, Eric V. McDonald, Sophie E. Baker. Integration of New Methods in Soils and Geomorphology Applied to Cultural Resources Management on Military Lands,
Geoarchaeology Workshop. 2008/10/20 03:00:00, . : ,

       TOTAL: **2**

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

<u>Received</u>   <u>Paper</u>

       TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

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<u>Received</u>   <u>Paper</u>

TOTAL:

Number of Manuscripts:

Books

<u>Received</u>   <u>Paper</u>

TOTAL:

Patents Submitted

Patents Awarded

Awards

NA

Graduate Students

<u>NAME</u>	<u>PERCENT_SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

<u>NAME</u>	<u>PERCENT_SUPPORTED</u>
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Thomas Bullard	0.59	
Eric McDonald	0.01	
Rina Schumer	0.01	
FTE Equivalent:	**0.61**	
Total Number:	**3**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics
This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME
Total Number:

Names of other research staff

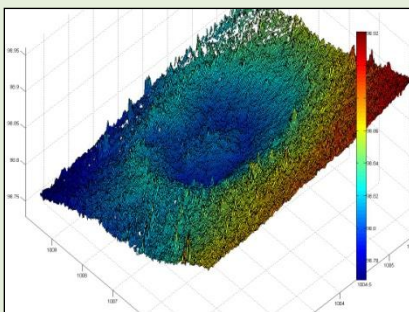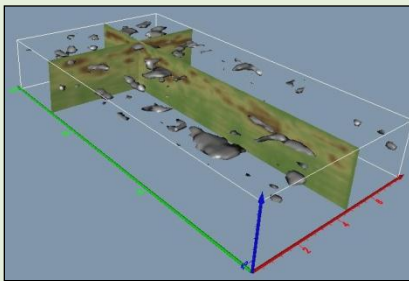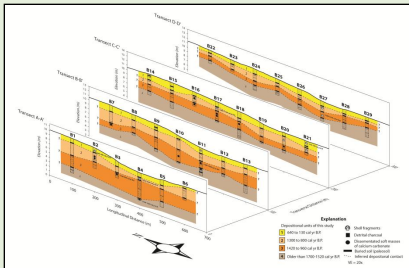| NAME	PERCENT_SUPPORTED
Steven Bacon	0.02
Sara Jenkins	0.09
Sophie Baker	0.01
Heather Green	0.01
FTE Equivalent:	**0.13**
Total Number:	**4**

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

See Attachments: Final Report

Technology Transfer

SCIENCE • ENVIRONMENT • SOLUTIONS

LanDPro: Landscape Dynamics Program

Final Report
Scientific progress and accomplishments

Thomas Bullard, Eric McDonald, Don Sabol, Rina Schumer, Steven Bacon, Sophie Baker, Todd Caldwell, Graham Dalldorf, Sara Jenkins, Roger Kreidberg, and Tim Minor

September 2011
(revised 09/12)

Prepared by

Desert Research Institute, Nevada System of Higher Education

Prepared for

U.S. Army Research Office

LanDPro: Landscape Dynamics Program

Thomas Bullard, Eric McDonald, Don Sabol,
Rina Schumer, Steven Bacon, Sophie Baker,
Todd Caldwell, Sara Jenkins, Roger Kreidberg,
and Tim Minor

Final Report

Scientific progress and accomplishments

Proposal Number: 52972-EV

Agreement Number: W911NF-07-1-0394

September 2011
(revised 09/12)

Prepared by

Desert Research Institute

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P.O. Box 12211

Research Triangle Park, NC 27709-2211

LANDPRO

ABSTRACT

LanDPro goals included enhancing and integrating soil, geomorphic, and hydrogeologic projects that DRI conducts for DoD and aims to improve the robustness and universality of existing tools in support of natural and cultural resources management on DoD installations. LanDPro activities included system-wide installation visits, briefings, geoarchaeology workshop, and developing cooperative and collaborative research efforts in support of natural and cultural resources management. These projects incorporate technology gained from ongoing ARO sponsored research at DRI. Overall progress on the project included:

- An International Conference on Military Geosciences to present research related to environmental management of military lands, past, present, and future

- A geoarchaeology workshop to help define areas of mutually beneficial geomorphic and archaeological research.

- Soil-geomorphic research in Mediterranean coastal environments, southern California, continues to add significantly to the knowledge base concerning landscape evolution and landscape responses to climate changes over the past few hundred to few thousand years, and is directly applicable to cultural and natural resources management in a variety of settings.

- Developed and applied a geomorphic-based archaeological sensitivity model at the U.S. Army Yuma Proving Ground.

- Developing field criteria for distinguishing cleared circle features having natural origins from cleared circle features having human origins.

- A predictive mapping component of a geomorphic-based archaeological predictive model was developed in collaboration with ASM Affiliates for the Marine Corps Air Ground Combat Center (Twenty-nine Palms) eastern and western expansion alternatives.

- Development of a geomorphic model to assess the archaeological potential for buried sites in collaboration with ASM Affiliates at Marine Corps Base Camp Pendleton utilizing subsurface stratigraphy derived from borehole cores, trenches, soil-geomorphology, and ground penetrating radar.

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PROJECT OVERVIEW

<u>Overall Goals and Objectives</u>

The Landscape Dynamics Program (LanDPro) was developed to build upon and integrate recently completed DRI projects on soil, geomorphology, hydrogeology, and cultural resources on DoD installations and helped to improve the strength and universality of existing tools in support of enhancing land stewardship. LanDPro goals included:

1. Enhancing layered GIS databases that permit rapid access to key soil, geomorphic, hydrologic, and terrain data

2. Integrating geomorphology, soils, and archaeology to complement and enhance cultural resource management strategies

3. Identifying key soil-geomorphic and hydrologic properties that influence habitats of threatened and endangered species

4. Assessing the sensitivity of training areas to future natural and human-induced disturbance

<u>Key Objectives:</u> The overarching theme of LanDPro was to expand ongoing research, initiate new research, and integrate new efforts with existing landscape studies developed in collaboration with military installations and private sector researchers. This helps to advance our knowledge of geomorphic controls operating on landscape systems as they relate to cultural resources management, threatened and endangered species habitat, and landscape erosion. Three principal objectives were:

• Develop methods of archeological site prediction enabling an increased efficiency of cultural resource surveys.

• Understand landscape dynamics and landscape evolution to better anticipate endangered species habitat and habitat responses to natural and anthropogenic disturbance.

• Develop and enhance geomorphic methods and tools that will provide land managers with the means to predict training area sensitivity to disturbance and geomorphic responses.

Significance and Army Value

Sustainable military readiness continues to be an important component of DoD as evidenced by recent DoD Sustaining Military Readiness conferences. Successful training to meet readiness and battlefield preparation relies upon the availability of large areas of landscape representative of in-theater battlefield environments. DoD administers military installations, training lands, and ranges around the U.S.; nearly 70% are located in arid to semiarid environments, which are current and projected to be future strategic sites for military operations. To meet goals of maintaining and sustaining safe, realistic military training environments while maximizing use for active training, DoD spends upwards of $100 million annually on land management, training impact mitigation, and range operations including inventory and management of natural and cultural resources as required by the National Historic Preservation Act (1966) and the Sikes Act Improvement Amendments (DoD Authorization Act, FY 1998). Many of these efforts primarily have been focused or conducted using single-discipline approaches (e.g., biology, archeology, GIS) and commonly lack scientific integration—especially with regard to soil science, geomorphology, and hydrology.

LanDPro was designed to undertake new research and integrate that with existing landscape studies to advance our knowledge of geomorphic controls operating on landscape systems as they relate to cultural resources management, threatened and endangered species habitat, and landscape erosion. This overarching goal includes undertaking research to (1) develop methods enabling archeological site prediction to increase efficiency of cultural resource inventory methods; (2) better understand landscape dynamics and landscape evolution to anticipate environmental responses to natural and anthropogenic disturbances that could affect endangered species habitat, and (3) develop geomorphic methods and tools that will provide land managers with the means to predict training area sensitivity to disturbance and geomorphic responses.

Approach

LanDPro research focused on military installations located in three principal physiographic settings: coastal, low interior hot deserts, and semiarid high desert, which correspond to marine, tropical/subtropical deserts, and Mediterranean divisions of the Bailey ecoregions of the United States (Fig. 0.1). This environmental focus is consistent with other DoD funded studies that have utilized Bailey's ecological framework to determine the general resiliency of training land to disturbance by tracked vehicle maneuvers. The resiliencies of the three ecoregions (tropical/subtropical and temperate desert; Mediterranean; marine) where we intended to conduct research in key topical areas are categorized as low, low-moderate, and high, respectively.
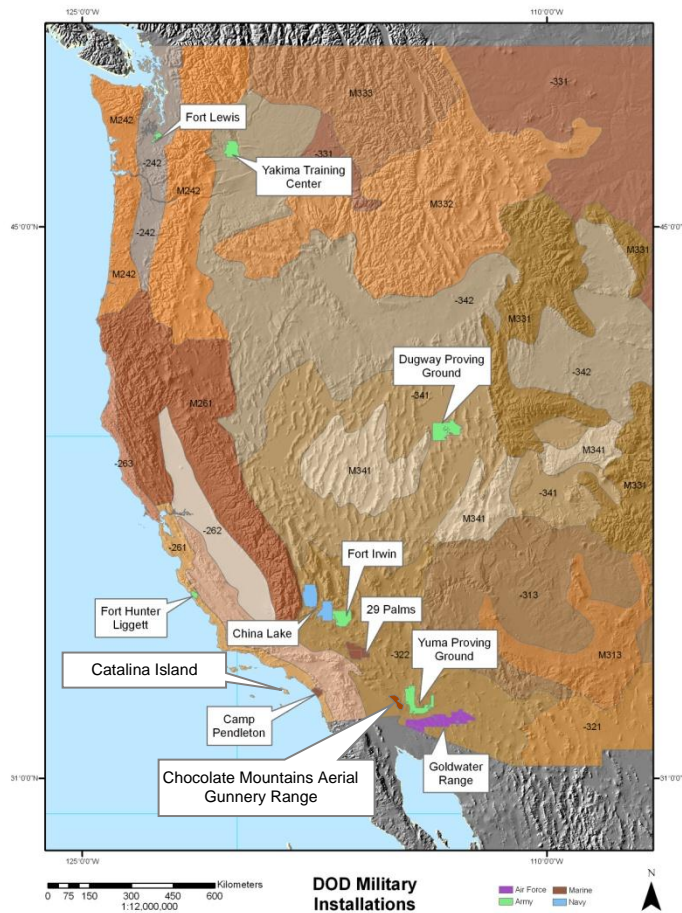
Figure 0.1. Map showing locations of anticipated projects within Bailey's ecoregions. Legend: 242 – Marine Division, Pacific Lowland Mixed Forest Province; 261 – Mediterranean Division, California Coastal Chaparral Province; 322 – Tropical-Subtropical Desert Division, American Semi-Desert Province; 341 & 342 – Temperate Desert Division, Intermountain Semi-Desert and Desert Province

- **Installation visits to establish dialogue with environmental managers.** This facet of LanDPro showcased our knowledge of landscape dynamics toward the goal of linking our landscape knowledge with concerns such as threatened and endangered species habitat, soil erosion, dust emission, fluvial system dynamics, and predicting locations of cultural resources. Installation site visits were designed to engage key installation personnel in discussing the potential for specific projects to determine the best sites for conducting research that could further the military's knowledge of the role of landscape dynamics on training land sustainability. On-site visits were arranged to select and develop specific projects through roundtable discussions and field inspections with installation personnel.

- **Archaeological predictive modeling and developing methods to distinguish anthropogenic from naturally occurring features**. We worked to expand and enhance our developing geomorphic-based archeological predictive model, which was initially developed in the Mojave Desert at the U.S. Army National Training Center at Ft. Irwin in collaboration with archaeologists from the U.S. Army Corps of Engineers - Construction Engineering Research Laboratory (CERL) in Champaign, Illinois and archaeologists at the Fort Irwin Cultural Resources Department. Modifications and enhancements to the geomorphic-based model made during LanDPro activities continue to make it more adaptable and applicable in a wider range of environmental settings. An integrated approach involved working with cultural resources personnel, employing rapid mapping techniques, and conducting follow-on field campaigns to characterize the natural environment and geomorphic processes associated with known archeological sites. A wide range of soil and geomorphic descriptors are used to categorize the complex desert landscape at known archeological sites. An extensive list of descriptors was developed to determine which components might prove to be most useful in development of the archaeological predictive model. Further evaluation of these descriptors continues to facilitate development of a short-list that will provide the greatest level of geomorphic information using the least number of descriptors possible. The descriptors used in the matrix are based on defined geomorphic principles and were selected to limit overlap among topographic position, morphology, deposit, and/or surface age. Moreover, we continue to refine a list of descriptors that can be developed for future use by archaeologists in the field to better incorporate geomorphic information during field collection of cultural resource data.

  The ability to distinguish naturally occurring features in the landscape from those produced by prehistoric inhabitants is crucial to many cultural resource managers at military installations in the desert southwest U.S. The difficulty in distinguishing naturally formed from man made archaeological features has resulted in cultural resource databases filled with recorded suspicious archaeological sites that have the potential to affect the training mission. Establishing solid field criteria that can be implemented by cultural resource managers and contractors to distinguish natural from anthropogenic features is of great value to both the cultural resources manager as well as the military installation.

- **Linkage between geomorphic processes and threatened and endangered species habitat**. Increasing our knowledge of the linkage between geomorphic processes and threatened and endangered species habitat was accomplished through initial site visits. These visits helped to identify high priority threatened and

endangered species and their locations, and determining the most appropriate and favorable locations to undertake field research projects. Goals of projects would be to: 1) characterize the natural environment and processes associated with threatened and endangered species; 2) synthesize existing biologic information with geology, geomorphology, soils, and biota; and 3) develop site specific prototype GIS models that integrate soil-geomorphic, biologic, and soil hydrologic parameters into a tool to forecast changes in geomorphic stressors (positive or negative) that affect threatened and endangered species habitat.

- **Application of soil geomorphology and soil hydrology in support of controlling environmental degradation.** This aspect was undertaken to advance and apply scientific knowledge to address training area degradation and enhance practices leading to training area sustainability. Military land damaged during training operations impacts nearly all facets of battlefield preparation. For example, fluvial erosion and deposition create transit hazards, obstacles and barriers to smooth transportation, and dust emission sources which can affect air and ground visibility, mechanical operation of vehicles, weapons, communications, and human health. Important to performing proper maintenance and rehabilitation is the knowledge that distribution of soils across the landscape and their role in geomorphology are important in controlling behavior of surface water, its interactions with near and subsurface soil conditions, and its utilization by plants. These are important factors that need consideration prior to training land rehabilitation and are addressed with the following approach that includes: 1) conducting field studies to characterize the geologic and geomorphic setting, soil-geomorphic and soil hydrologic conditions, landscape age and evolution, and sensitivity to disturbance; 2) conducting site specific soil hydrology characterization with *in situ* soil hydrology tests to determine field characteristics, coupled with laboratory analysis of soil and hydrology samples to predict natural and disturbed soil moisture conditions on different landscape components and ages; and 3) synthesizing existing soil-geomorphic and soil hydrology information into an interactive GIS database and develop a site-specific prototype GIS model that is able to integrate soil-geomorphic, soil and landscape age, soil hydrologic parameters, topography, and climate into a tool that helps identify specific areas vulnerable to differing levels of disturbance.

ACCOMPLISHMENTS

LanDPro was approved and funded in June 2007. Throughout the duration of the program efforts were directed at continuing to establish and maintain lines of communication at key installations, providing briefings, and developing projects that

implement, integrate, and leverage emerging knowledge gained from other DoD sponsored research carried out at DRI (for example, Desert Terrain Forecasting, Global Military Operating Environments, Characterization of Natural Testing Environments for Military purposes).

Communications and Site Visits. Installation site visits and telecommunications were undertaken throughout the program and during the final year of funding. Visits involved informal briefings regarding LanDPro goals and other ongoing DoD sponsored research conducted by DRI as well as ARO Annual PI and ARO West Coast PI Programmatics Review Meeting review meetings at the U.S. Army Corps of Engineers – Engineer Research and Development Center (ERDC) – Construction Engineering Research Laboratory (CERL) Champaign, Illinois, Las Vegas, Nevada, Reno, Nevada, University of California at Redlands, and Barstow, California. Site visits and/or communications included:

U.S. Army Corps of Engineers, ERDC-CERL, Champaign, IL (PI review meeting)

ARO West Coast PI Programmatics Review Meeting, Barstow, CA

U.S. Army National Training Center, Fort Irwin (NTC), CA

U.S. Army Yuma Proving Ground (YPG), AZ

U.S. Army Reserve Fort Hunter Liggett (FHL), CA

U.S. Army Dugway Proving Ground (DPG)
- Barry M. Goldwater Range West (BMGR West)
- Chocolate Mountains Aerial Gunnery Range (CMAGR)

U.S. Army Fort Drum, NY

U.S. Marine Corps Base, Camp Pendleton, CA

U.S. Marine Corps Air Station Yuma (MCASY), AZ

U.S. Navy, Naval Facilities Engineering Command, Southwest Division, San Diego, CA

U.S. Navy Special Warfare Group - Desert Warfare, Chocolate Mountains

U.S. Navy, San Clemente Island Range

Catalina Island Conservancy and UCLA Field Archaeological Program (lecture presentation and collaborative research proposal development)

University of Kansas, Lawrence, KS

9th International Conference on Military Geosciences, Las Vegas, Nevada

Project Development. An important aspect of LanDPro was the interaction and collaboration with installation managers to ensure the most pressing needs are addressed in the most effective manner. Potential projects related to natural and cultural resources management, including archeological predictive modeling were discussed and developed; in some cases projects were developed in collaboration with partners in the private sector.

Although funding at the installation level restricted some project implementation, scopes of work were developed for studies related to the following and many may be continued well into and beyond FY 2011 as funding allows.

SUMMARY OF MAJOR ACCOMPLISHMENTS

- Conducted workshop "Integration of New Methods in Soils and Geomorphology Applied to Cultural Resources Management on Military Lands." [FY09] (report included as Appendix A)

- Held the 9th International Conference on Military Geosciences, June 19-24, 2011, in Las Vegas, Nevada. Theme was military operations in desert environments. [FY11] (abstracts volume included as Appendix B)

- Archaeological predictive modeling at US Army Yuma Proving Ground [FY09/FY11]

- Soil-geomorphic and hydrologic research to establish criteria for distinguishing cultural vs. human origin of cleared circles in cultural resources management, US Army Yuma Proving Ground integrating LiDAR (Light Detection and Ranging), GPR (ground penetrating radar), surface mapping, and subsurface stratigraphic characterization [FY09/FY12]

- Collaborative research in applied geomorphic, geotechnical, geophysical, and archaeological techniques in exploration for subsurface archaeological sites, Marine Corps Base Camp Pendleton, CA, collaborative with government contractor [FY09/FY10]

- Ongoing research of landscape history and geomorphic response to land use change and climate change in a Mediterranean climate coastal setting, Catalina Island, CA [FY07/10]

- Participation with UCLA International Field Archaeology Program on Catalina Island, CA in education and application of geomorphology to the study and prediction of archaeological sites in a Mediterranean coastal climate setting [FY08/FY11]

- Threatened and endangered species habitat at Fort Hunter Liggett (U.S. Army Reserves) [proposed FY09; placed on hold for funding reasons];

- Predictive modeling for cultural resources inventory, application of mapping and remote sensing techniques for assessing resource material sourcing at MCAS Yuma (Barry M. Goldwater Range West) [initiated FY09, placed on hold];

- Archaeological predictive modeling at the U.S. Navy Desert Warfare Group (SEALS; Chocolate Mountains Aerial Gunnery Range) [initiated FY09, placed on hold].

1. *Landscape history and response to land use change and climate change in a Mediterranean coastal setting, Catalina Island, CA*

An area of great interest to cultural resource managers, particularly in the coastal and inland Mediterranean environment of central coastal and southern California, concerns site location, modification (erosion or deposition), and burial through geomorphic processes. Work was initiated in cooperation with the Catalina Island Conservancy on Catalina Island in offshore southern California (Fig. 1.1) and continues to focus on the geochronology of landscape components and depositional evidence of landscape change in response to changes in vegetation and climate. The results of the Catalina studies have direct application to both cultural resources management (e.g., site burial) and range management (possible landscape changes in response to alterations in climate) particularly to installations along the coast of California (US Army Ft. Hunter Liggett, USMCB Camp Pendleton, U.S. Navy San Clemente Island Range) as well as installations inland and in other climate settings.
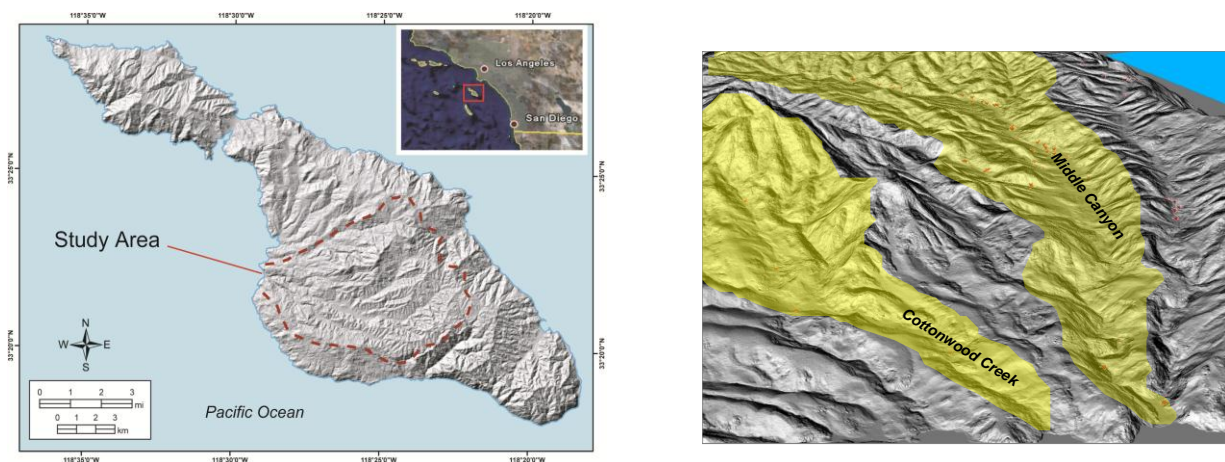
Figure 1.1. Map showing the location of Catalina Island (left) and the areas of study (right).

The alluvial deposits in stream valleys of Catalina Island, which span the past few thousand years, record cycles of erosion and deposition (Fig. 1.2). Yet there is continuing difference in opinion about the role of intense grazing on landscape erosion on the island (Fig. 1.3). Anecdotal evidence has suggested that intense erosion on Catalina Island occurred as a result of a long period of overgrazing that began in the early 18th century and continued until the mid 20th century. However, we found that despite major precipitation events in the mid and latter 20th century, there is no evidence for massive erosion and deposition in the past 150 years, particularly when compared to depositional packages of the previous few thousand years (Fig. 1.2).
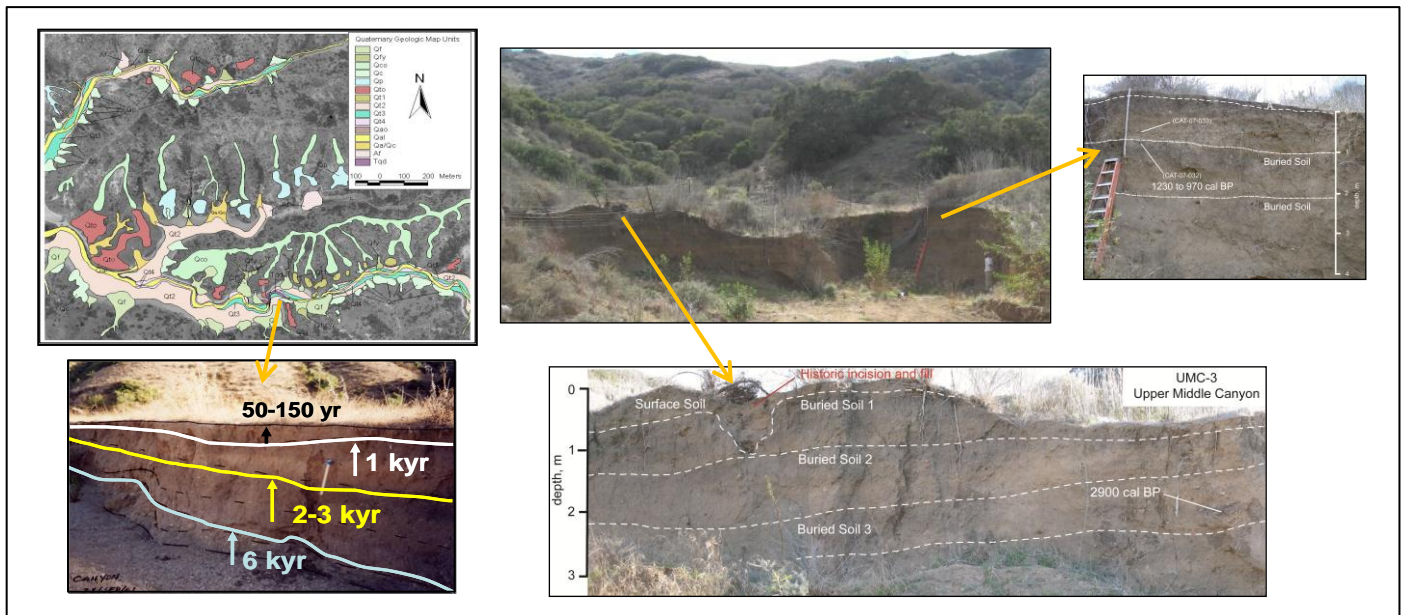
Figure 1.2. Example of geomorphic and Quaternary geologic mapping to delineate differing ages of landforms and stratigraphic units for a part of Catalina Island (top left). Lower photos illustrate dated stratigraphic units showing sediment packages representing erosion and deposition prior to grazing activities of the past 150 years (lower left) and thick packages of various ages of alluvium representing hillslope sediment contribution (upper and lower right). The colored lines in the lower left photograph represent the tops of depositional packages separated by intervals of stability and soil development. Approximate time of deposition is shown by the ages in thousands of years (kyrs). Deposition related to grazing is represented by the sediment package above the white line.
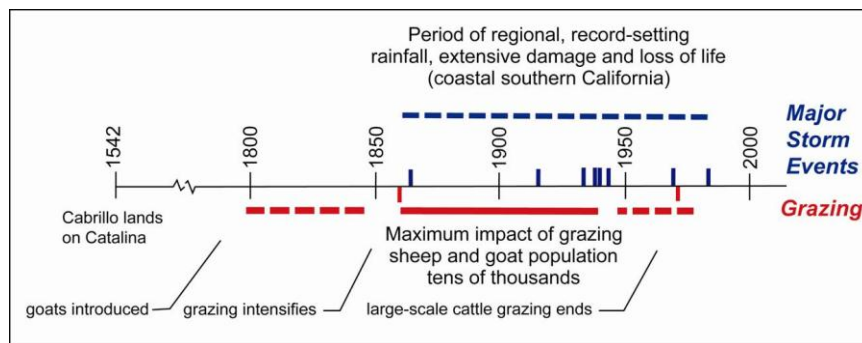
Figure 1.3. Graph showing the grazing timeline (red lines) for Catalina Island. Significant, regional precipitation events occurring in the 19th and 20th century in southern California (blue lines) caused numerous deaths and widespread flood damage occurred in the 20th century, but were not accompanied by notable, widespread erosion on Catalina Island.

When considering erosion, particularly anecdotal evidence and general descriptions, the question becomes what constitutes "a lot" of erosion. To begin to address this

question, a highly simplified sediment budget was developed to gain a general sense of the volume of hillslope sediment required to fill incised stream channels to a depth of about 30 cm to about 1.5 m since the period of grazing occurred (Fig. 1.4). The model assumed a highly uniform and simplified mode of sediment transport across the entire hillslope and delivery into main stem channels. Results of the analysis (Table 1.1) indicate that to fill main stem channels 30 cm deep would only require about 30% of available hillslope material entering the channels at a denudation rate of about 0.1 mm/yr. Filling channels about 1.5 m deep would accommodate most of available hillslope material at the same denudation rate. The principal problem with these results is that there is very little evidence of historic sediment in the channels, thus an apparent absence of hillslope response to grazing.
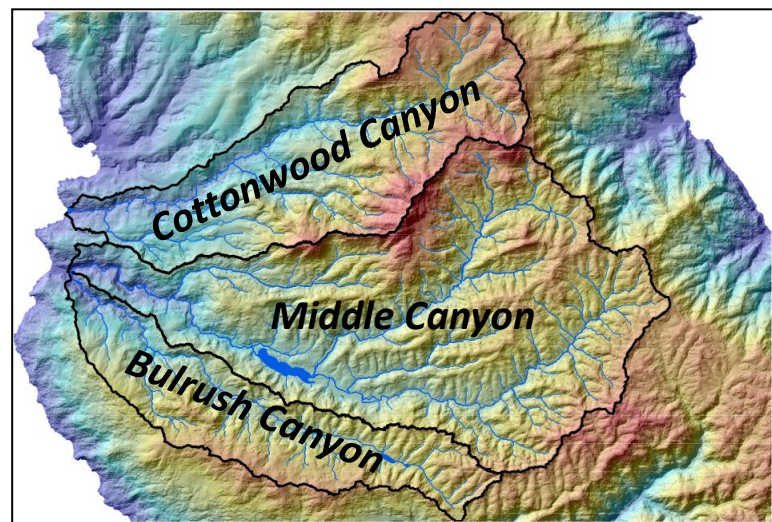
Figure 1.4. Watersheds selected for analysis of sediment contribution from hillslopes.

Table 1.1. Results of sediment volume contributions from hillslope erosion.

		Volume	Volume Channel (m^3)	
Catchment	Area (km²)	Hillslope Sediment	Fill Depth 30 cm	Fill Depth 200 cm
Bulrush Canyon	9.3	137773	34547	230316
Middle Canyon	27.6	406851	142972	953146
Cottonwood Canyon	14.7	218442	41168	274450

Because the assumptions of hillslope erosion are extremely simplified, and grazing appears to be insufficient to cause widespread erosion, we considered other scenarios for mobilizing hillslope deposits. Field evidence, as well as evidence observed in archival and modern photographs, suggest that landslide activity has the potential to contribute large amounts of sediment to streams. A map of landslides was developed (Fig. 1.5) from which estimates of sediment volumes were obtained. Generally speaking, the landslide area represents less than about 1 percent of the area of the three watersheds (Table 1.2). Yet the volume of landslide deposits represented by the mapped landslides is about 20 percent of the total volume of sediment on the hillslopes. Despite the potential for landslides to contribute large volumes of sediment per unit area, the current frequency of landslide activity is incapable of supplying the amount of sediment needed to fill channels. The results have strong implications for the geomorphic response to grazing activities as well as processes responsible for the repeated cycles of deposition and erosion represented by the prehistoric valley fill deposits.
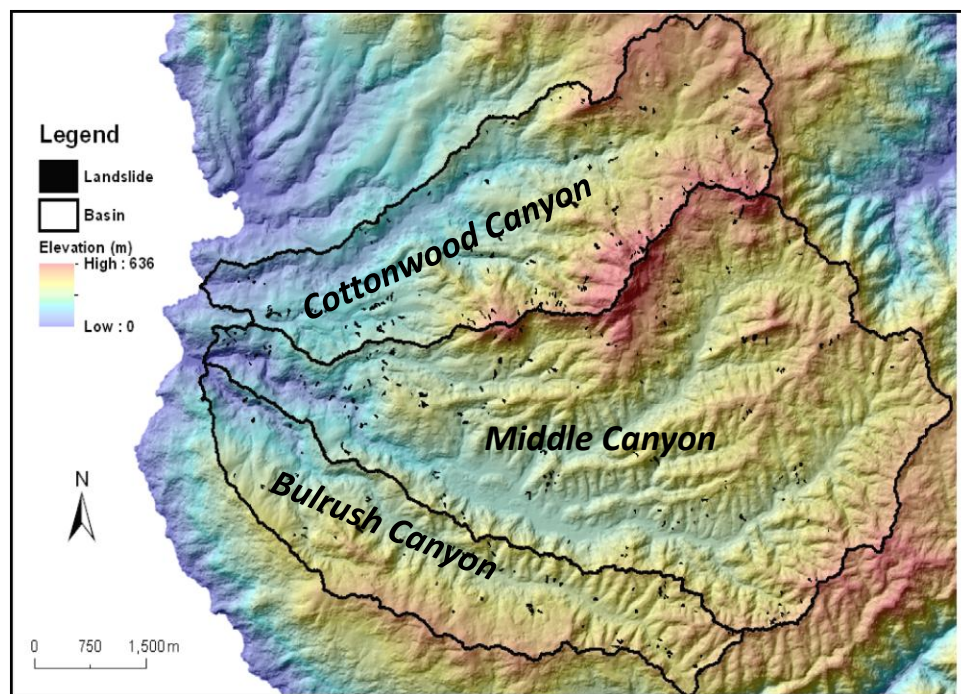
Figure 1.5. Map of landslides in Cottonwood, Middle, and Bulrush canyons at Catalina Island.

Table 1.2. Summary of landslide distribution, area, and volume estimates for Bulrush, Middle, and Cottonwood canyons at Catalina Island

Catchment	Area (km^2)	n	Area (m^2)	Volume (m^3) [1m thick]	Hillslope Volume (m^3)
Bulrush Canyon	9.3	85	54070	26829	137773
Middle Canyon	27.6	205	118226	58614	406851
Cottonwood Canyon	14.7	159	105900	51847	218442

Analysis the geochronology of the sediment packages observed in valley fill indicates a linkage between documented changes in climate, as recorded in nearby offshore cores and documented rapid global climate changes, and episodes of hillslope erosion, valley filling, and stream incision over the past several hundred to few thousands years (Fig. 1.4). These results cast new light on the timing and magnitude of landscape response to climate change. Research on the landscape evolution and response to environmental change in this Mediterranean climate are continuing. Recent results include additions to the geochronology that will more tightly constrain depositional and erosional events.
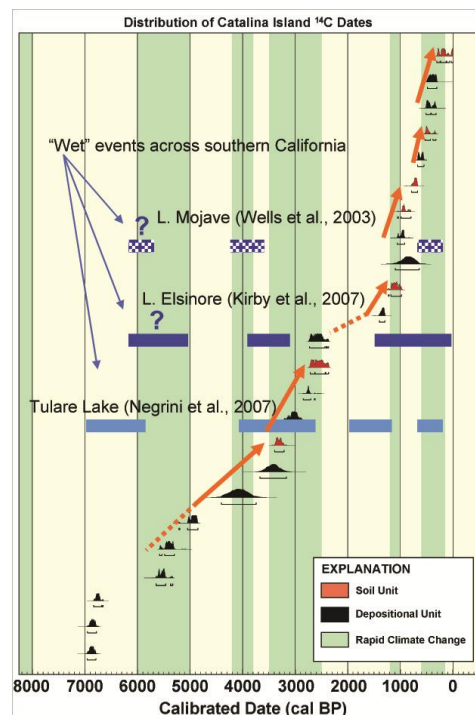
Figure 1.6. Graph showing radiocarbon dates, soil units, and seven depositional events distinguishable by soils that developed in the intervals between depositional events. Superimposed on the graph are periods of rapid global climate change (green vertical lines [after Mayewski et al., 2004]), and regional "wet" events across southern California (McDonald and Bullard, 2008a, b).

Importance to ARO: The results of the Catalina studies have direct application to both cultural resources management and range management (particularly to installations along the coast of California (US Army Ft. Hunter Liggett, USMCB Camp Pendleton, U.S. Navy San Clemente Island Range) as well as installations inland and in other climate settings. The investigations on Catalina Island benefit cultural resource managers by helping to identify areas of potential burial of archaeological materials and to design appropriate treatments in support of the training mission. These investigations also help the natural resources managers in understanding potential landscape changes in response to perturbations in climate as well as land use activities.

2. Development of a geomorphic-based archaeological sensitivity model for cultural resources management at U.S. Army Yuma Proving Ground

Background. The application of geomorphic principles to help understand human prehistory in the context of desert landscape evolution has been an integral part of archaeological investigations for decades (Waters, 1992). The use of geomorphology to define and characterize landscape components conducive to preserving archaeological materials, also has been in use for several decades; however, it is only in recent years that the knowledge of soil-geomorphic relationships has been applied to, and integrated with, cultural resource management strategies. Intensified research efforts on American Southwest desert geomorphic systems in the 1970s and 1980s began to shed light on landscape evolution and the relationships between landscape stability, landscape age, desert soils, and the development and significance of desert pavements (Wells et al., 1984; McFadden et al., 1987; McFadden et al., 1989; McDonald, 1994). In recent years, use of this knowledge in archaeology has increased to the point of routine inclusion in cultural resource management programs (e.g., McDonald and Bullard 2003; McDonald et al., 2004).

Approach. This study expanded upon an existing conceptual framework of the role of geomorphology in archaeological modeling. DRI began working with researchers from ERDC-CERL and Fort Irwin Cultural Resources Department to develop a conceptual, geomorphic-based archaeological model (Ruiz, 2002; McDonald and Bullard, 2003; McDonald et al., 2004; Ruiz et al., 2007). The DRI model was based on straightforward associations of geology, geomorphology, and archaeology and estimates the relative favorability (i.e., sensitivity) or potential of landscape elements to contain either surface or buried archaeological sites. For example, relatively intact lithic scatters, campsites, and quarry sites were found preserved on stable geomorphic surfaces formed on parent materials derived from volcanic rock sources and Tertiary deposits containing cobbles of rock type suitable for tool making. These same types of sites were rarely found on landscapes formed on deposits derived from coarse-grained igneous rock sources, such as granite and quartz monzonite because these landscapes are inherently unstable and not prone to preserving intact sites or containing abundant suitable stone-tool resources. However, different site types, such as natural rock shelters and long term habitation sites were associated with the coarse-grained igneous rocks.

Our premise is that if our conceptual model were applied at the U.S. Army Yuma Proving Ground (YPG) it would indicate a dominance of sites on the most stable landscape units developed on deposits derived from fine-grained igneous rocks. At YPG, these landscape units would be predominantly alluvial fan surfaces (Qf1, Qf2, Qf3

of McDonald et al., 2007) of Pleistocene and Pleistocene-Holocene transition age developed in areas dominated by volcanic parent material. Furthermore, the conceptual model would likely indicate a dominance of lithic scatters, quarry sites, and cleared circle features on those older alluvial fan surfaces formed on sediments derived from extrusive igneous rocks.

Modeling efforts applied to cultural resource management and treatments of data range from simple intuitive Boolean and weighted sensitivity intersection models to increasingly sophisticated multivariate regression models (e.g., Altschul et al., 2004, 2005; Nagle and Cushman, 2009). Regardless of the model chosen, it is the initial sound, science-based conceptual model that frames the problem and leads to formulating important questions to address. Selecting the appropriate variables for use in the model is very important. In desert regions the geologic and geomorphic expression in the landscape is obvious and clearly exerts a degree of control on ecosystems and human activity. Integrating geology and landscape into archaeological models capable of predicting site location is a worthy and desirable objective, yet the proper effective use of geomorphology in modeling, particularly in deserts, has yet to occur (e.g., Bullard et al., 2009); hence, many archaeological models fall short of expectations.

The geologic and geomorphic-based archaeological model developed for this study relied on the integration and geospatial analysis of available data sets for geomorphology, geology, and archaeology at YPG and the statistical treatment of data using nonparametric classification and regression tree (CART) analysis. The geospatial treatment of the digital data consisted of simple overlay analyses using Environmental Systems Research Institute ArcGIS software (Fig. 2.1). The geomorphology and Quaternary geology was based on extensive prior work at YPG by DRI (e.g., McDonald et al., 2007; Bacon et al., 2008, 2010) and bedrock geology for parent material determination was based on the digital geologic map for Arizona (Hirschberg and Pitts, 2000). Archaeological data collected over several decades at YPG was used in the development and calibration of the model.

Findings.

The geomorphic-based, conceptual archaeological predictive model developed at the U.S. Army National Training Center at Fort Irwin, California in the Mojave Desert (McDonald and Bullard, 2003; McDonald et al., 2004), provided a basis for developing a simple statistical model for YPG that could handle stratified geomorphic data with relative ease. Our conceptual model predictions were substantiated by the statistical analyses in this study. For example, for prehistoric surface sites, particularly lithic scatters and cleared circles, were shown to have a very strong statistical association with geology, parent material, and landform age. The agreement between the Fort Irwin

conceptual model and the YPG statistical model is, in large part, because the geomorphic settings and geomorphic processes are similar at YPG and Ft. Irwin. Subtle differences, particularly in the distributions of rock types, availability of lithic resources for tool making, and lesser amounts of coarse-grained igneous rocks (e.g., quartz monzonite, granite) result in different site type distributions and locations in the landscape. The results of both of our models support the initial findings of Lashlee et al. (2001), which suggested archaeological site distribution is intimately related to the landscape.
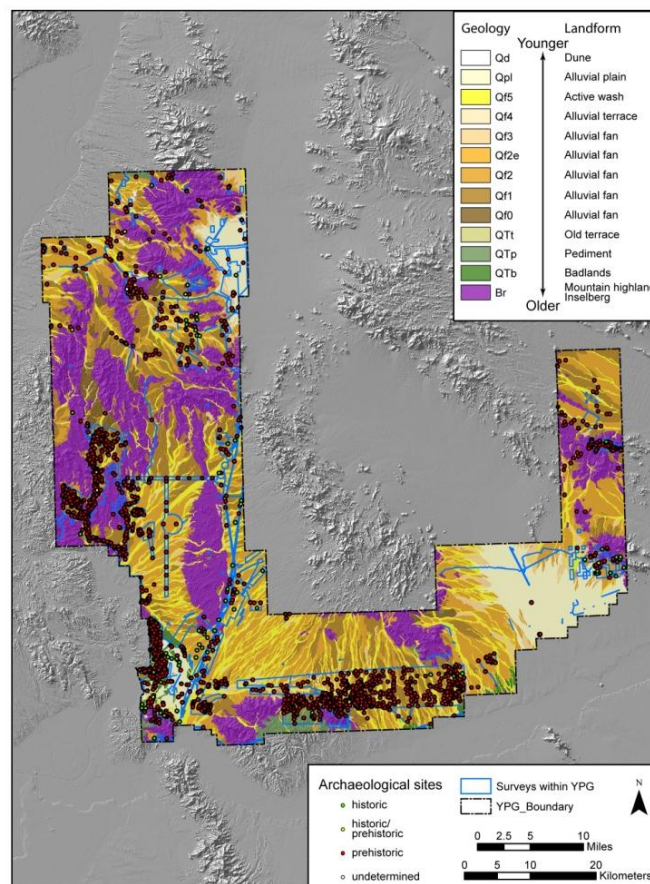
Figure 2.1. Geologic map of YPG showing landforms, archaeological survey boundaries, and all archaeological sites at YPG.

The CART analysis formed the basis for assigning relative sensitivity of landforms and bedrock to the presence of archaeological sites (Fig. 2.2) and the resulting model (Fig. 2.3). A clear statistical association exists among the occurrence of archaeological sites and site types and the parent material and landforms at YPG. Prehistoric site occurrence has a strong association with Pleistocene alluvial fans, badlands, and

bedrock (mountain highlands and inselbergs). Sites found on Pleistocene alluvial fan surfaces comprise more than 80 percent of prehistoric sites and sites situated on alluvial fan surfaces comprise more than 95 percent of sites located on alluvial landforms (Table 2.1). The overwhelming majority of prehistoric sites are found on alluvial fan surfaces having parent material derived from volcanic source rock or in bedrock areas composed of volcanic bedrock (Table 2.2). Despite the apparent success rates of the model, there are limitations in terms of accuracy and scale. Accuracy is influenced by the available data and scale is problematic anytime small scale maps are used to analyze data collected at much larger scales. Obtaining accurate GIS data for archaeological resources has been a common challenge in modeling (e.g., Altschul et al., 2004, 2005) and has been cited previously as a factor that contributed to the discouraging results of earlier models developed for YPG (Altschul, 2007). Despite our efforts to ensure we were using the best available data, attempts to develop a strong, sound sensitivity model were hindered somewhat by deficiencies in data quality (e.g., block survey boundaries that match site boundaries, poor location information). We circumvented part of the challenge by carefully examining the YPG data base and utilizing only the most accurately located sites for the analysis.
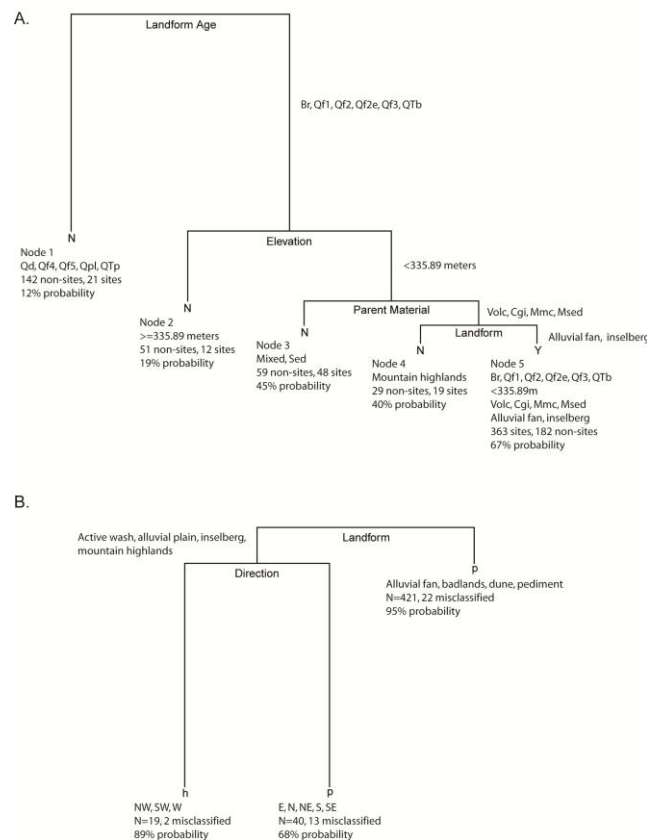
Figure 2.2. Classification and regression trees for (A) the presence or absence of archaeological sites and (B) historic versus prehistoric sites .

Importance to ARO: The geology, soils, and geomorphic-based archaeological sensitivity model emphasizes the relationship between landscape evolution, and the location and preservation of cultural resources. The model can provide the cultural resources manager with a simple, intuitive, yet scientific-based way to identify areas of higher potential for archaeological site occurrence. This allows the cultural resources manager to prioritize efforts and allocate resources in the most economic and beneficial way.

Figure 2.3. Sensitivity model for surface archaeological sites at YPG.

Table 2.1. Summary of all archaeological sites by temporal component, landform, geology, and relative age

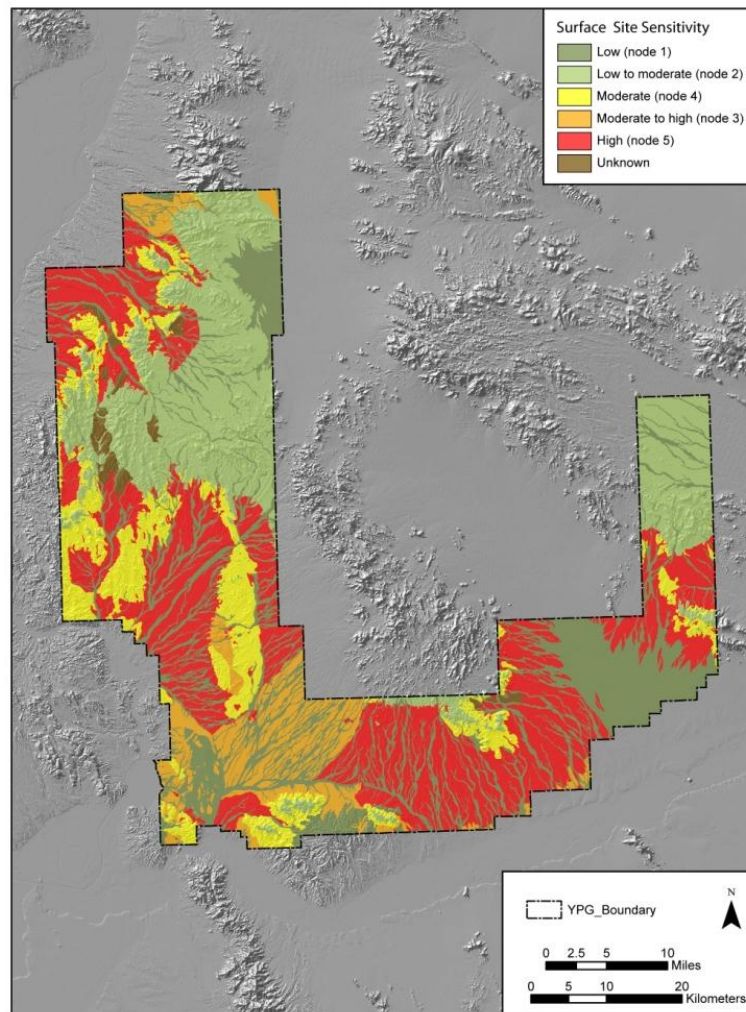| Landform Geol/Rel age*	Mountain highlands Br	Inselberg Br	Pediment QTp	Badlands QTb	 Qf0	Alluvial fan Qf1	 Qf2	 Qf2e	 Qf3	Alluvial terrace Qf4	Active wash Qf5	Alluvial plain Qpl	Dune Qd
Prehistoric sites	165	14	20	130	7	508	712	17	48	4	80	38	3
Historic sites**	24	2	1	0	0	14	28	0	4	1	13	9	0
Bi-component sites	3	2	0	1	0	6	6	0	0	0	1	0	0
Sites of unknown age	1	0	0	0	0	0	4	0	1	0	0	0	0
Total sites	193	18	21	131	7	528	750	17	53	5	94	47	3
Percent of total sites	10.3	1.0	1.1	7.0	0.4	28.3	40.2	0.9	2.8	0.3	5.0	2.5	0.2
Sites per area (km^2)***	4.2	9.0	1.7	4.9	3.5	4.1	4.6	3.7	2.1	0.7	0.9	0.9	1.2

 * Geologic map unit and relative age of unit; oldest to youngest: Br>QTp, QTb>Qf0>Qf1>Qf2>Qf3>Qf4>Qf5, Qpl, Qd; Br = bedrock;
  QTp = Quaternary-Tertiary pediment; QTb = Quaternary-Tertiary badland; Qf = alluvial fan; Qpl = alluvial plain; Qd = eolian sand dune
 ** Including modern sites; excluding two linear sites spanning multiple landforms.
 *** All surveyed areas within the installation.

Table 2.2. Summary of sites having accurate and mostly accurate locations by temporal component and parent material

Parent Material Lithology	Volcanic	Coarse-grained intrusive	Sedimentary	Metasedimentary	Mafic metamorphic	Mixed
Hirschberg and Pitts' (2000) geologic units	Kv, Ka, Qb, Qr	Mzgr, TKi, TKg	Mzs, TKs, Tms, QTs	Mzsc	Mzgn	-
Prehistoric sites	480	10	40	10	30	43
Historic sites*	23	9	0	0	0	12
Bi-component sites	7	3	0	0	0	0
Sites of unknown age	1	0	0	0	0	0
Total sites	511	22	40	10	30	55
Percent of total sites**	76.5	3.3	6.0	1.5	4.5	8.2

*including 2 modern sites.

**all accurate/mostly accurate sites

3. Soil-geomorphic research to establish criteria for distinguishing origins of cleared circles, U.S. Army Yuma Proving Ground

Background. Archaeological surface features (e.g., trails, rock alignments, geoglyphs, and cleared circles) can represent substantial challenges to the cultural resource manager because their extent may be obscured or modified by biologic and geomorphic processes, their specific use may be not well known, and origin is not always clear. The inclusion of non-anthropogenic, naturally occurring features into the archaeological site record presents substantial challenges in terms of fiscal and human resources, unnecessary site protection and site treatment, and the potential for restricted access to training or testing areas. The challenge to interpreting various types of surface features is determining unequivocally whether such features are anthropogenic or formed by natural processes. Identifying and interpreting surface features requires consideration of both natural and anthropogenic origins, thus requiring collaborative efforts among archaeologists and Earth scientists. Furthermore, distinguishing between anthropogenic and natural features is critical for forward progress in both areas of research.

The focus of this component of LanDPro is on cleared circles, which are roughly circular shaped features about 1 to 3 m diameter that have a smooth, interior shallow depression either devoid of desert pavement clasts or sparsely covered with clasts having varnish development notably weaker than pavements on the adjacent land surface (Fig. 3.1). Common to many areas of cleared circles are active and relict shrub mounds similar in many respects to cleared circles of human origin.
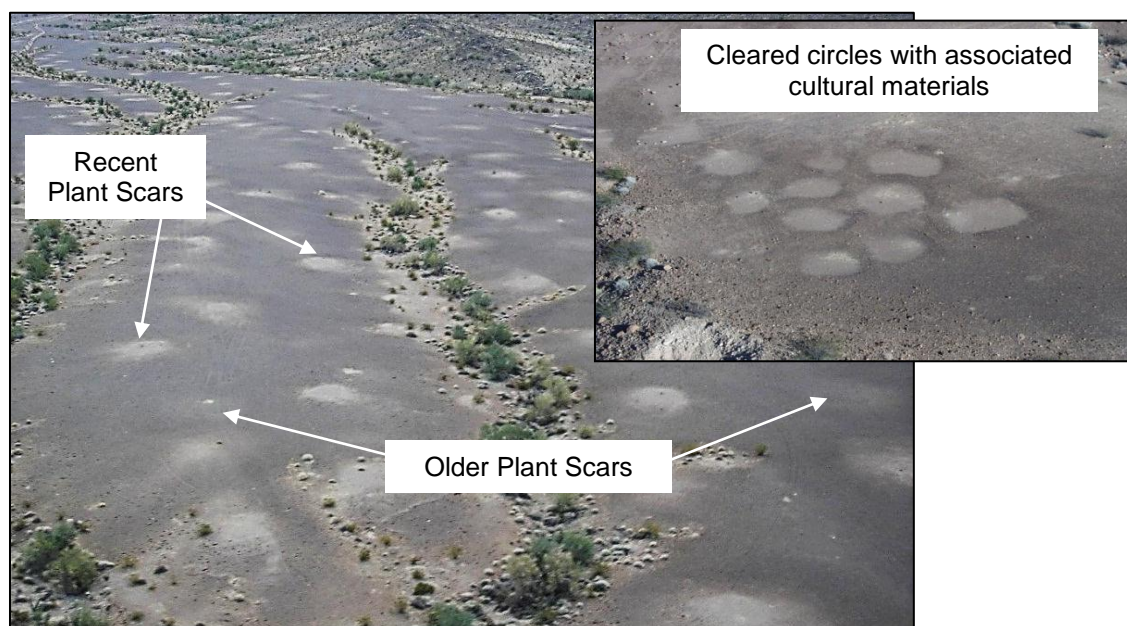

Figure 3.1. Examples of cleared circles at Yuma Proving Ground and common on other DoD installations in the desert southwest US. More than 1000 of these have been recorded as archaeological sites.

Cleared circles are prevalent on desert pavement surfaces across the U.S. Southwest and northern Mexico, yet their origin is uncertain. Many hundreds have been recorded as cultural features, attributed to deliberate scraping of the desert pavement by prehistoric inhabitants to create a more comfortable living (sleeping) surface (Dosh and Marmaduke, 1992; Marmaduke and Dosh, 1994; SAA, 2005). Alternatively, many cleared circles have been shown to result from biologic and pedogenic processes (McDonald et al., 2001; McAuliffe and McDonald, 2006). At YPG the origin of cleared circles is of particular interest in part because of the large number of cleared circles (>1,000) recorded as archaeological sites that require special treatment and consideration before range use, but also for the information generated that is useful for the archaeologist interested in a better understanding of prehistoric use of cleared circles having human origins. In collaboration with YPG cultural resources personnel, a research program was designed with the purpose of developing recognizable field criteria for distinguishing naturally occurring cleared circles from those created by humans. The approach taken for this ongoing research project includes soils and geomorphology studies integrated with trenching and ground penetrating radar (GPR), and characterization of the surface of cleared circles using ground-based Light Detection and Ranging (LiDAR).

Approach

The working hypothesis is that detailed surface characteristics of manmade and natural cleared circles should differ and could be used to distinguish them and, in turn, enable development of a model for the evolution of naturally formed cleared circles. The working model for development of cleared circles originating as plant is related to bioturbation associated with plant mounds, subsequent abandonment, and collapse of the plant mound (Fig. 3.2). In such a scenario, naturally occurring soil horizons beneath plant scars should be disturbed, whereas beneath cleared circles of anthropogenic origin, the subsurface soil horizons should be intact (Fig. 3.3, 3.4). Studies of the cleared circles focused on the soil stratigraphy and the formation of the raised berm on the perimeter of the cleared circles. Surface characterization studies include surficial geologic and geomorphic mapping, subsurface characterization of soils (Fig. 3.5), application of non-invasive GPR using a Noggin SmartCart 250 MHz Ground Penetrating Radar unit (Fig. 3.6), and use of a Light Detection and Ranging (LiDAR) system to gather millimeter scale data to capture subtle variations in surface microtopography to help understand cleared circle formational processes (Fig. 3.7).
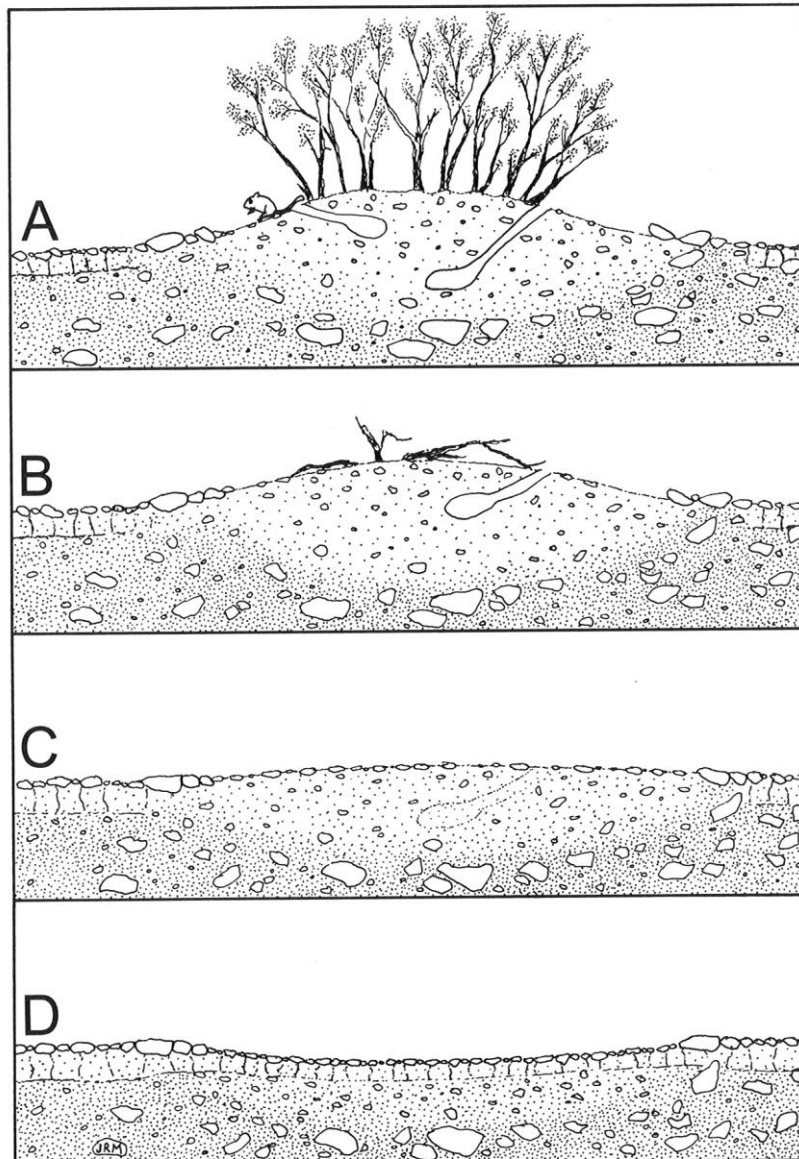
Figure 3.2. Conceptual model of the natural formation of a cleared circle from an abandoned plant mound. (A) mound forms around plant due to eolian sediment accumulation and bioturbation, desert pavement surface and Av horizon are disrupted, larger stones displaced to margin of canopy by animal burrowing; (B) plant dies and bioturbation decreases; (C) compaction occurs as burrows collapse, settling occurs, and initiation of Av horizon formation; (D) further compaction. formation of slight depression; Av horizon redevelops across the scar.

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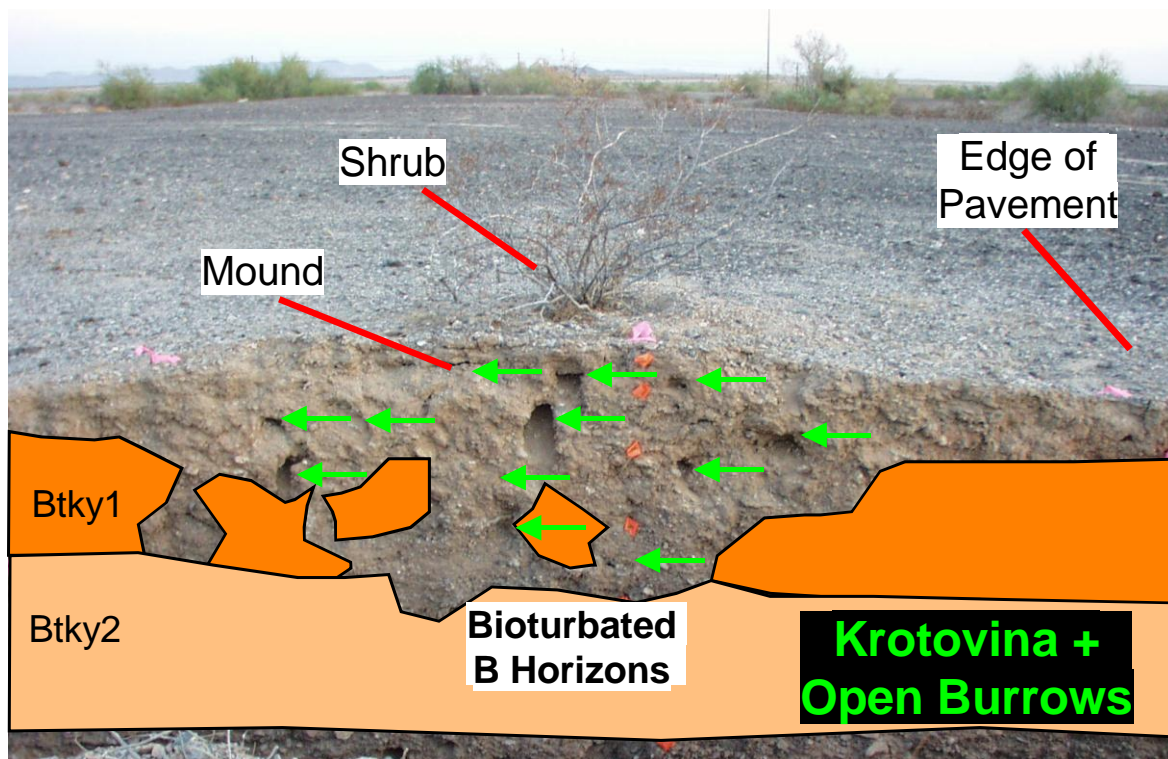
Figure 3.3. Typical soil stratigraphy observed beneath a plant mound. Rodent burrows effectively reduce the bulk density of the soil material, and eolian material accumulates around plant. Detailed soil stratigraphy records disruption and fragmentation of underlying soil horizons. (from McDonald et al., 2011)
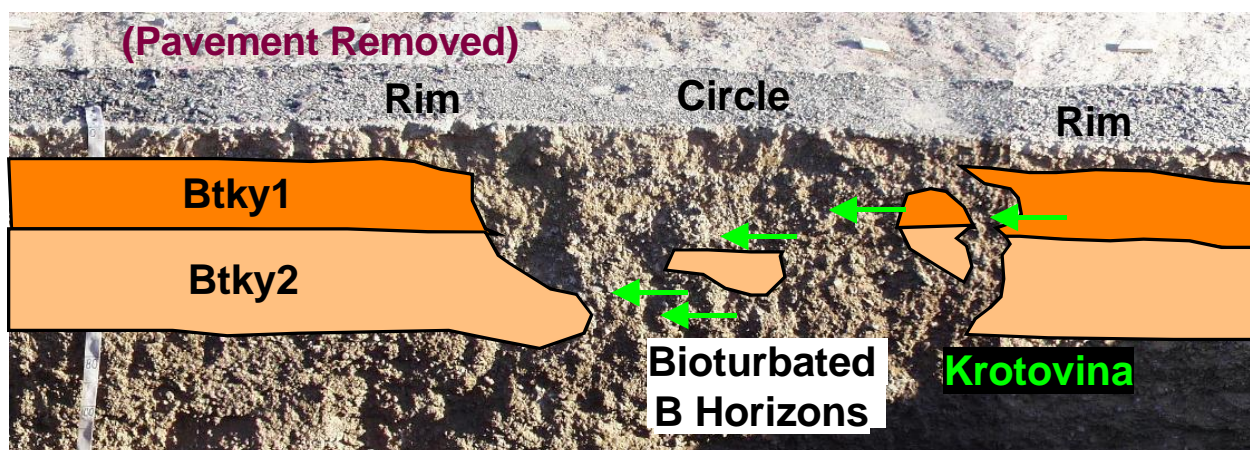
Figure. 3.4. Disruption of soil stratigraphy beneath well-formed cleared circle indicating a probable natural formation process for this feature. (from McDonald et al., 2011)
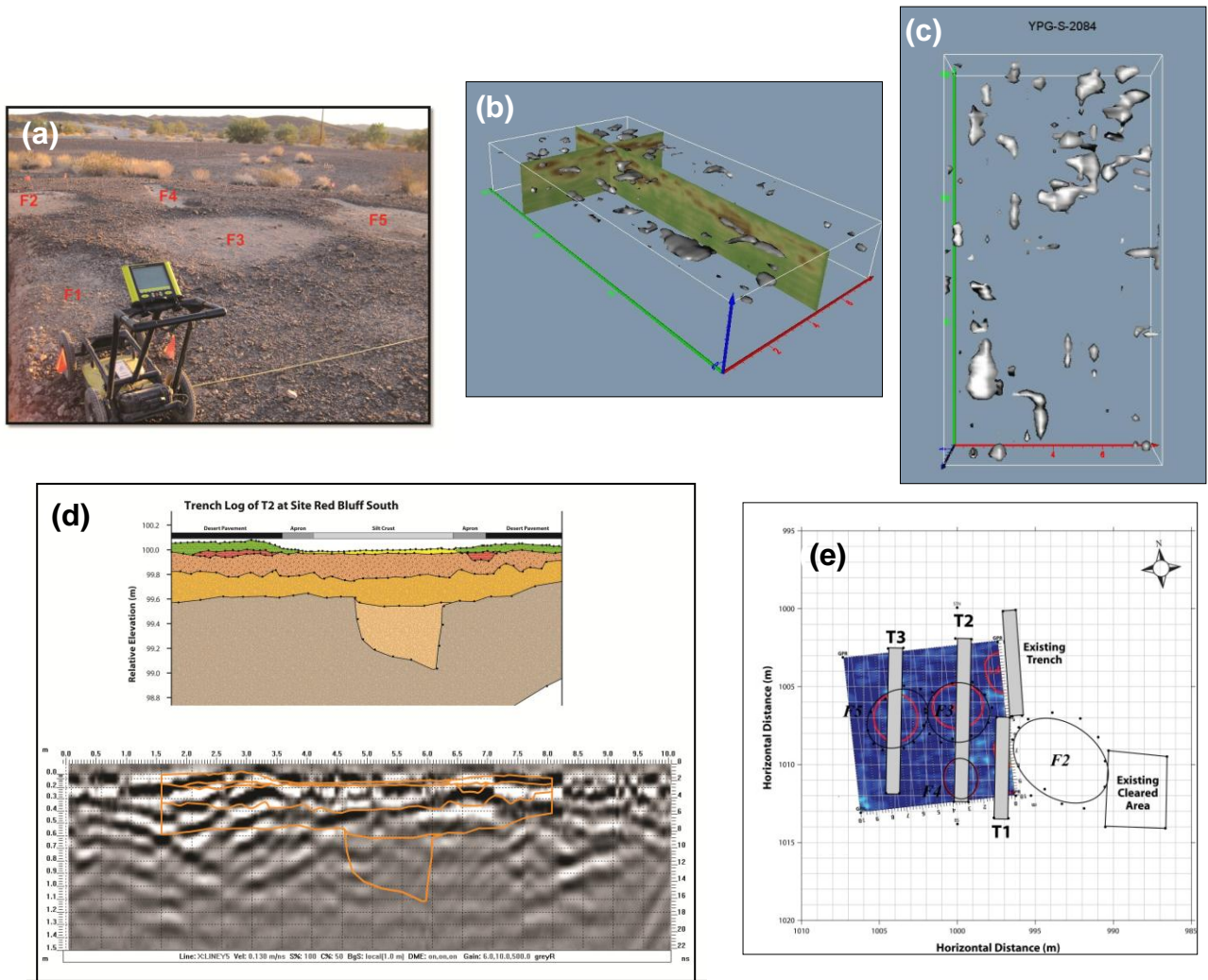
Figure 3.5. Examples of GPR application in the study of cleared circles at YPG. (a) Noggin SmartCart 250 MHz GPR unit at the Red Bluff south site; (b and c) 3-D depictions of subsurface anomalies consistent with discontinuous horizontal strata (e.g., disrupted soil horizon); (d) stratigraphic log at T2, showing surface topography and thickened Av horizon (red and green coded units) and corresponding GPR profile; and (e) site map and GPR anomaly map at the Red Bluff site shown in (a).

Figure 3.6. Examples of the application of LiDAR in the study of cleared circles at YPG. (a) Leica Geosystems ScanStation™ II; (b) Cyclone visualization snap shot of the LiDAR scan of cleared circles showing well-defined smooth central area (high laser reflectance) and apparent topography associated with the rim; (c) Microtopographic profile across cleared circle along A-A' (McDonald et al., 2011).

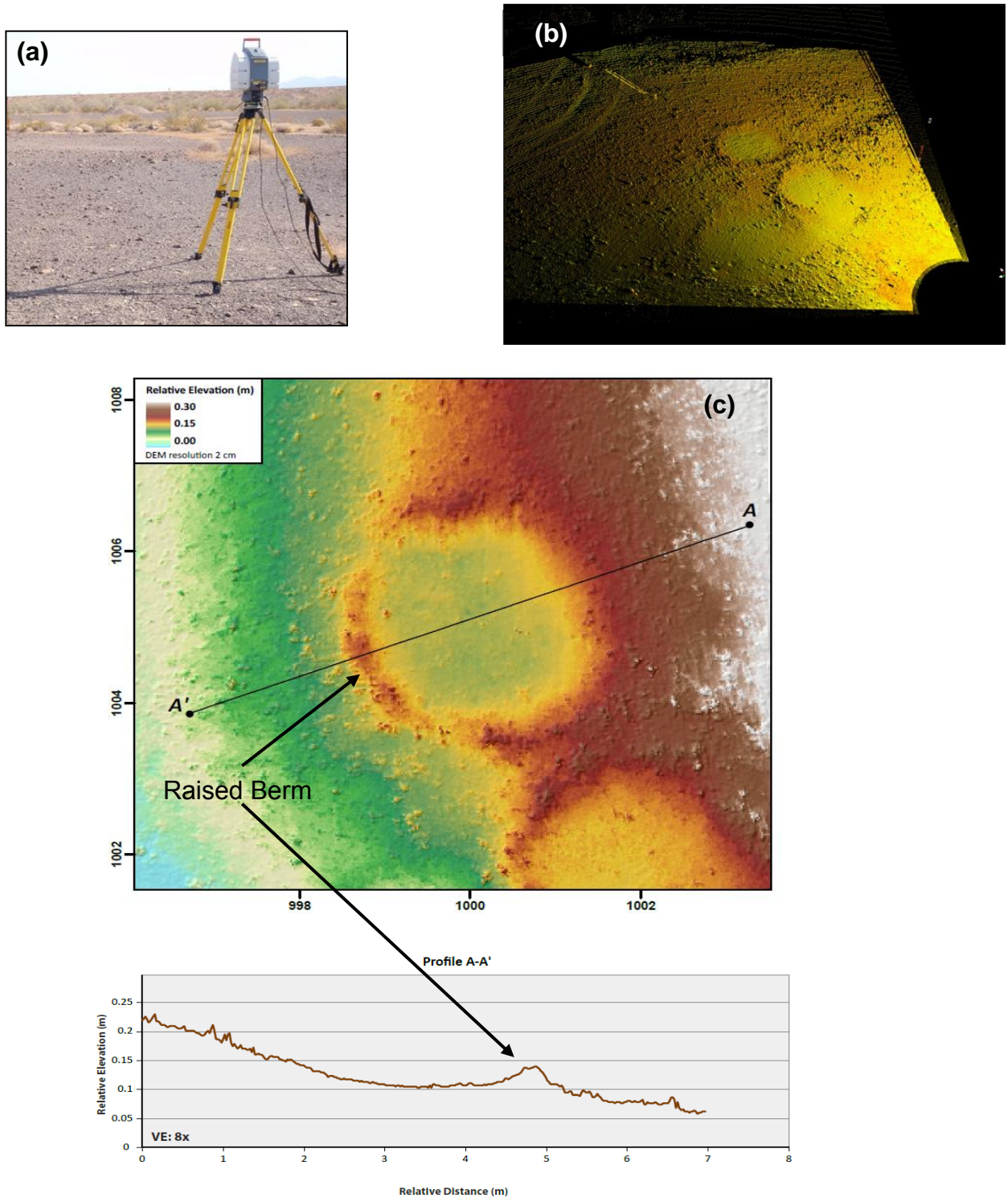**Findings.** Although data is still being collected and analyzed, encouraging results are emerging. Detailed analysis of the soils and surface morphology of cleared circles, active shrub mounds, and WW II tent sites (i.e., pavement areas cleared by soldiers) located on alluvial fan surfaces at YPG reveal obvious, measurable differences in surface morphology and the integrity and composition of subsurface soil horizons. Topographic relief associated with berms along the outer margin of natural cleared circles is due to a thickening of the Av horizon (Figs. 3.7, 3.8). Although the exact mechanics are still being investigated, based on initial results, a set of field criteria can be developed to allow archaeologists to differentiate natural from anthropogenic cleared circles. It is important to note, however, that the criteria will not allow one to determine whether or not a cleared circle was used by prehistoric inhabitants.
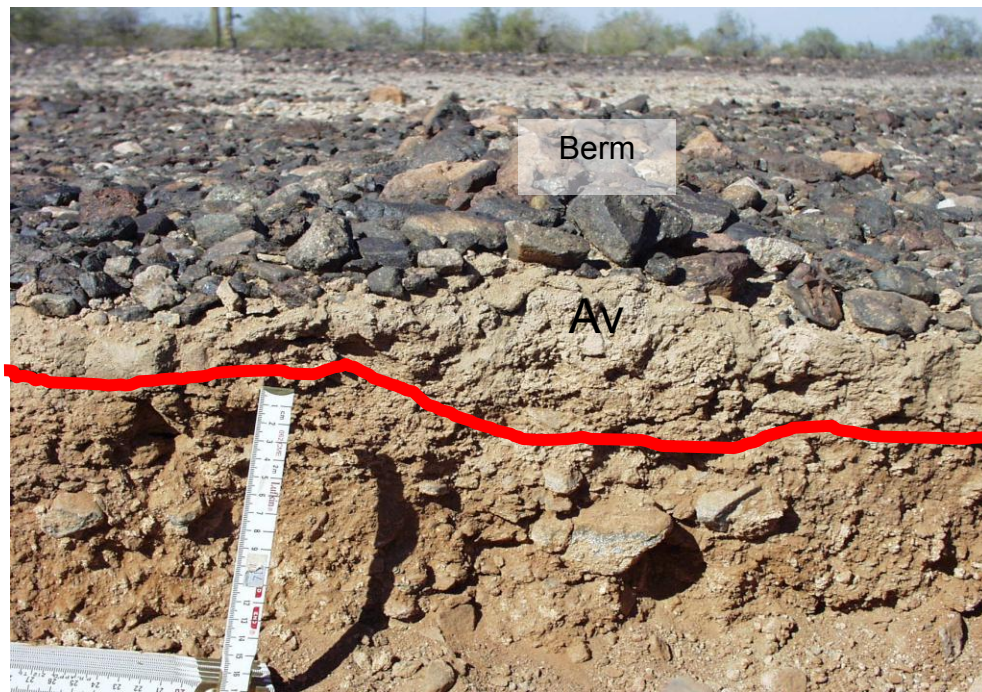
Figure 3.7. Photograph showing thickening of the Av horizon beneath the perimeter berm.

The process of forming of naturally occurring cleared circles remains a focus area of the current ongoing study and we are optimistic for future progress. GPR results for surveys conducted across cleared circles of suspected natural origin show subtle, detectable anomalies in the subsurface consistent with disruption of soil profile by biologic processes as observed in detailed stratigraphy in trenches across cleared circles. In contrast, areas cleared by human activities typically have intact soil horizons beneath them, whereas active and relict plant mounds are characterized by disrupted subsurface soil horizons. Trench stratigraphy is revealing important Av horizon

characteristics that appear to be associated with the cleared circle berm (Figs. 3.7, 3.8). Apparent topographic changes across the berm are also captured in LiDAR data further suggesting a possible connection between the soil-geomorphic-biologic system and the development of cleared circles.
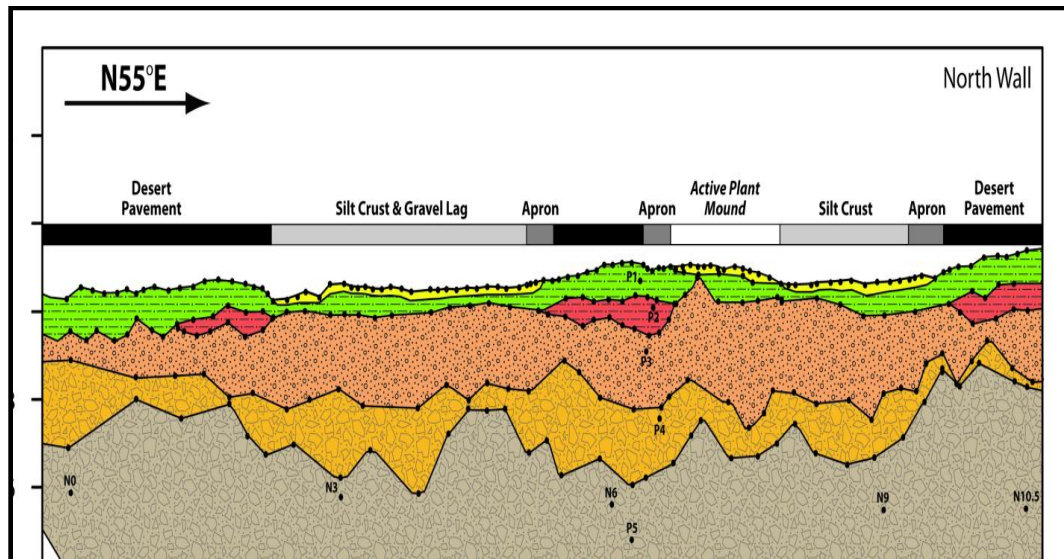

Figure 3.8. Detailed trench log through cleared circle and plant mound showing thickening of the Av horizon (green and red) at the margin of cleared circle (McDonald et al., 2011).

These results, as well as observations of the apparent regular spatial distribution of cleared circles, indicate that most of the cleared circles at YPG probably were created by long-term interactions between desert shrubs (e.g., creosote bush) and small burrowing mammals (e.g., rodents) that tend to inflate the area and disrupt pavement formation and pedogenesis. Although many of the cleared circles recorded at YPG may be natural phenomena, the age and distribution of these features may hold important information about changing environmental conditions and may record long-term trends in regional climate, which comprise important data for interpreting human occupation of the area.

Importance to ARO: Training and testing on military lands must take into consideration, among other important things, natural and cultural resources. The large numbers of surface features identified as cultural resources that are included in archaeological site records can create significant challenges to the cultural resource manager in economic terms of fiscal resources, manpower, and the design and implementation of treatment plans, as well as logistical planning for training and testing. Having the ability to potentially reclassify large numbers of features as naturally occurring, based on sound scientific research, could allow the cultural resources manager more freedom in planning and managing their programs, strategizing the allocation of fiscal and human resources, and satisfying mission requirements.

4. Rapid soil-geomorphic mapping component of an archaeological predictive model, U.S. Marine Corps Air Ground Combat Center (29 Palms), CA

DRI collaborated with ASM Affiliates of Carlsbad, California to develop a geomorphic map as a component of an archaeological sensitivity model in support of cultural resources management at the U.S. Marine Corps Air Ground Task Force Training Command (MAGTFTC), Marine Corps Air Ground Combat Center (MCAGCC) at Twenty-nine Palms, CA. The focus was to provide a linked soil, geomorphic, and geologic map and data to support ASM's development of an archaeological sensitivity model for the proposed MCAGCC expansion areas. Our experience from developing a conceptual model that relates geomorphology and prehistoric cultural resources at nearby U.S. Army National Training Center, Fort Irwin lead us to (1) recognize predictable relationships among the landscape, landform age, soil development, geology, archaeological site types, site integrity and site preservation and (2) be active proponents for the inclusion of soil-geomorphic mapping and analyses in cultural resource management. This project was used as a test of DRI's ongoing expert-based global geomorphic mapping for Desert Terrain Forecasting (DTF) applied at the installation level.
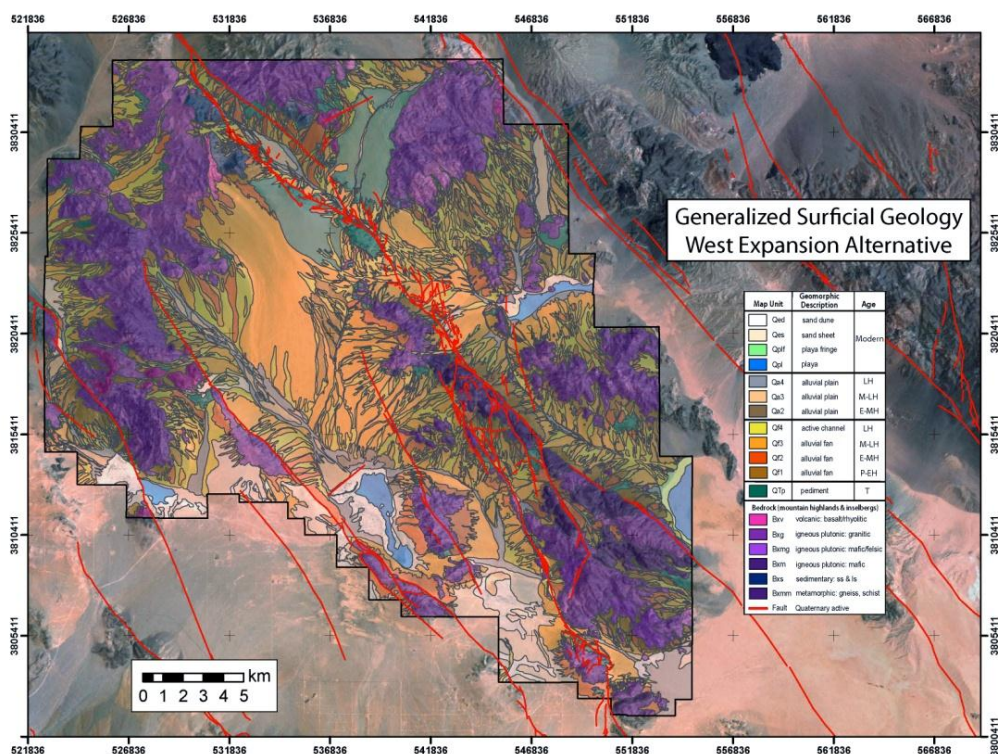

Figure 4.1. Generalized surficial geology map of the MCAGCC West Expansion Alternative overlain on a color digital imagery base.

The maps produced (Fig. 4.1 and 4.2) considered the geomorphic evolution and Quaternary geology in a complex bedrock setting in a region of high tectonic activity as well as the presence of a system of playa lakes and eolian systems. Individual map units were attributed with landform type, parent material characteristics, relative age, and soil characteristics. In the desert environment, it has been demonstrated that archaeological sites are commonly associated with particular landform types and this attribute alone is very powerful information for the archaeologist. The parent material attribute contributes to the stability of alluvial landforms (i.e., alluvial fans) as well as alerting the archaeologist to potential lithic procurement sites. The relative age and soil attributes provide important information relative to the long term stability of landforms and the archaeological potential. Using only the geomorphic, soil, and geologic information, strong inferences can be made regarding the archaeological potential of the region.
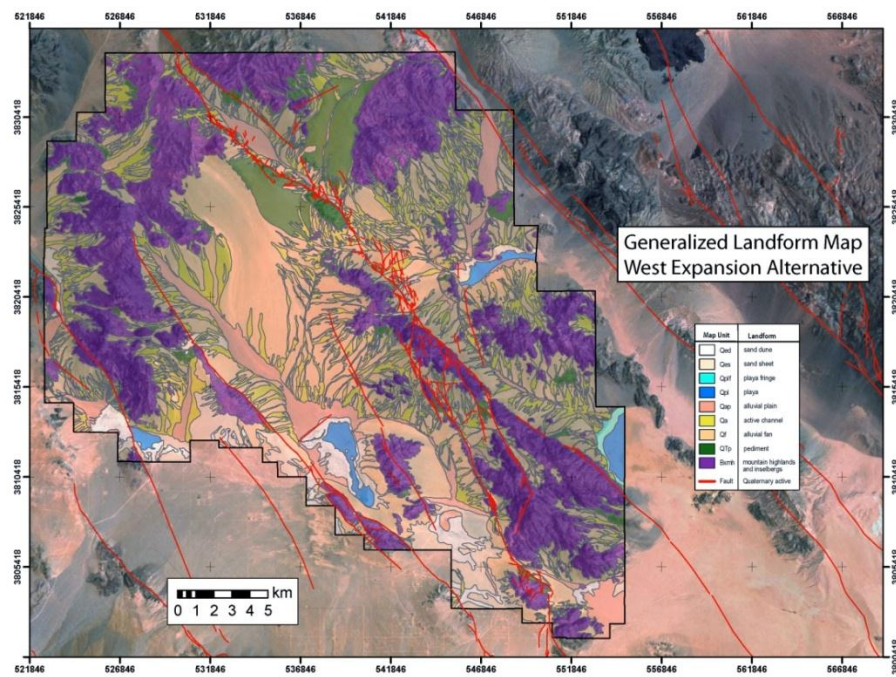
Figure 4.2. Generalized landform map of the MCAGCC West Expansion Alternative overlain on a color digital imagery base.

The landform map was integrated with a dataset that included slope, aspect, proximity to water sources, geology, landform, and geomorphology. From this integration a probability map was developed (Fig. 4.3) to highlight the areas of high, medium, or low probability of containing archaeological sites. Results continue to show the strong linkage between cultural resources and soil-geomorphic and geologic variables. Predictable relationships between soils, landforms, and geology allow the assignment of relative levels of favorability of encountering cultural resource sites. The

ability to reduce the number of variables helps to streamline the process and focus efforts. The absence of quality of geomorphic maps at a proper scale and detailed soil-geomorphic data precludes the ability of most installations to conduct these types geomorphic and archaeological investigations. Yet, these are necessary to support efficient and timely cultural resource surveys.
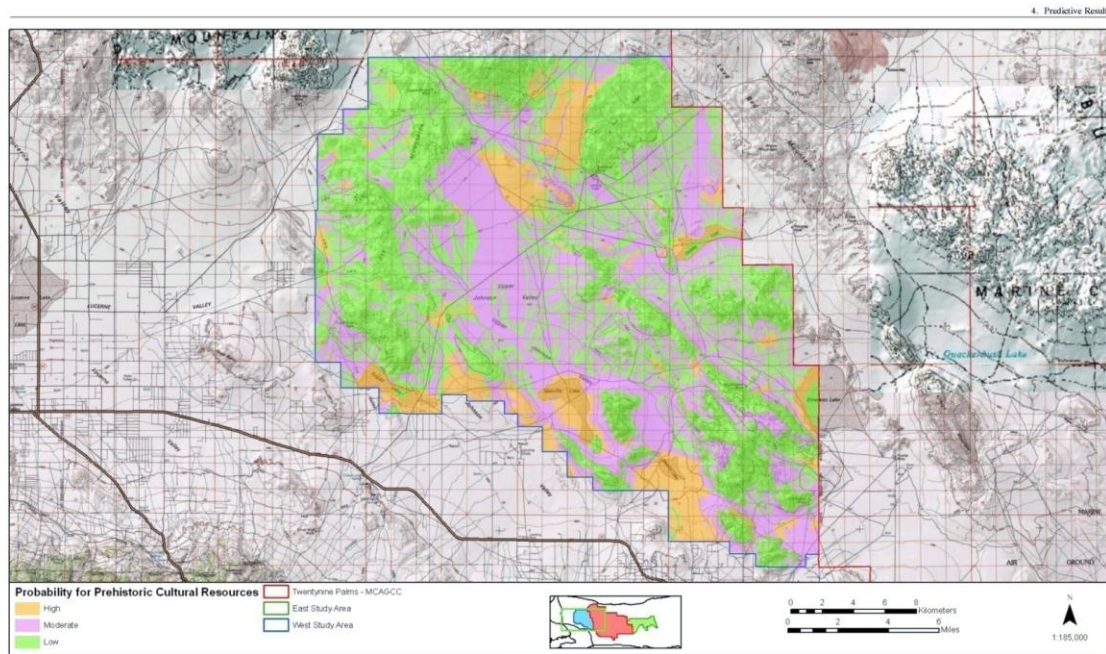
Figure 4.3. Probability map of the western expansion area at Twentynine Palms, MCGACC

Importance to ARO: The application of mapping methods and attributing techniques utilizing technology initially developed by DRI for their ARO sponsored Desert Terrain Forecasting program serves as a test and refinement of the ability to rapidly map terrain and assign surface and shallow subsurface characteristics to map units. This technology can be transferred to cultural resource managers who have a need to develop geomorphic based predictive models to help define areas of archaeological potential, design treatment plans, and effectively allocate fiscal and human resources when developing management plans for inventory and management of cultural resources.

5. Developing a geomorphic-based model for assessing buried archaeological site potential using geologic, geomorphic, and geophysical techniques, U.S. Marine Corps Base Camp Pendleton, CA.

A buried archaeological site comprises material evidence of human activity that is buried either by anthropogenic or natural depositional processes. Cultural resource management challenges relating to buried sites include finding sites that are not evident from surface inspection alone, interpreting site context (e.g., in situ or reworked), and interpreting site paleo-environment.

This study was to develop a model for assessing the archaeological potential in alluvial sediments along San Mateo Creek at U.S. Marine Corps Base Camp Pendleton (MCBCP). In an effort to develop the model, a collaborative research program was developed with ASM Affiliates (Carlsbad, CA) and included subsurface exploration including mechanical coring and detailed stratigraphic logging of 30 deep cores, soil stratigraphic descriptions in 15 trenches, soil geomorphic analyses, and ground penetrating radar to explore for anomalies indicative of buried archaeological sites.

Previous archaeological excavations and geological coring near archaeological sites along San Mateo Creek recovered limited remains from a Late Prehistoric near-surface component of the site, as well as traces a Late Archaic component 1.5 to 2 m below the surface (e.g., Iverson and Becker 2008; Pearl and Waters 1999; Reddy 2005; Waters et al. 1999; Waters 1996; Kern, 1995). These studies (e.g., Byrd et al. 1995; Kern 1995) developed general scenarios for the geomorphic evolution of the lower reaches of coastal river systems based on limited subsurface information and concluded that the local geologic setting, tectonics, climate, and sea level change were largely responsible for the observed stratigraphic architecture.

The packages of sediment found in the current study area up to 8 m deep and date to less than 3000 years. Longitudinal transects and transverse stratigraphic transects (Fig. 5.1 and 5.2), and a valley cross-section (Fig. 5.3) constructed from interpreted borehole cores and trenches and show general thickening of deposits to the west and suggest relatively continuous deposition over the past 3000 years or more and the deepest part of the San Mateo Creek valley is at or near the present position of San Mateo Creek against the western margin of the valley, principally as a result of tectonic tilting.

Studies in recent years have shed light on local to regional Holocene climate change and rapid global climate change events (Mayewski et al. 2004). Studies of cores have documented significant, rapid changes in late Holocene hydrologic conditions in nearby Lake Elsinore (Kirby et al 2004). The Lake Elsinore studies concluded that a wet early Holocene was followed by a long-term drying trend throughout much of the Holocene accompanied by low variability in the climate from about 3800 to 2000 cal yr B.P.,

followed by a wetter more variable climate up to the present, which is consistent with rapid global climate change events.

Figure 5.1. Transverse stratigraphic transects perpendicular to San Mateo Creek presented in actual scaled grid space showing correlated depositional units, buried soils, presence of detrital charcoal and shell fragments, and radiocarbon dates.   Transverse transects show deposits thickening to the west toward the San Mateo Creek.
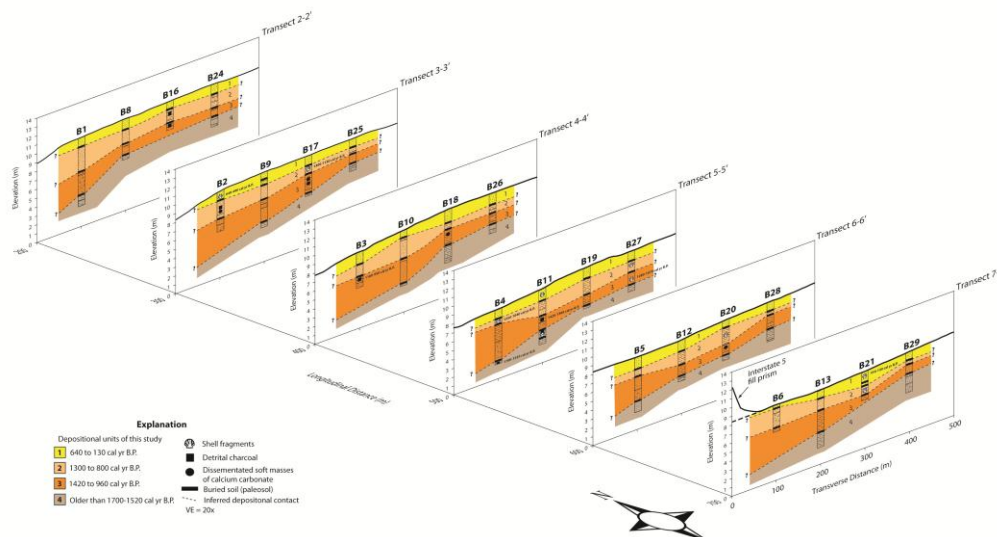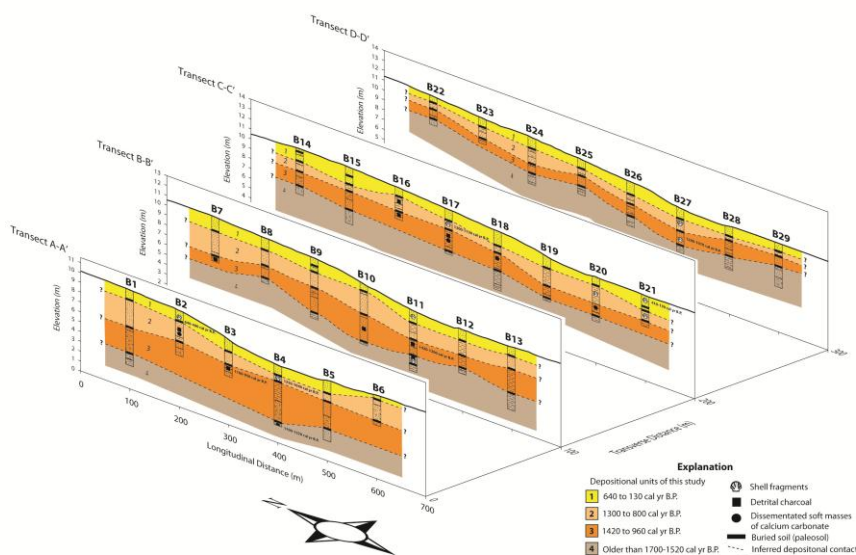

Figure 5.2. Longitudinal stratigraphic transects parallel to the San Mateo Creek presented in actual scaled grid space showing correlated depositional units, buried soils, presence of detrital charcoal and shell fragments, and radiocarbon dates.   Longitudinal transects show a general thickening to the south and west.
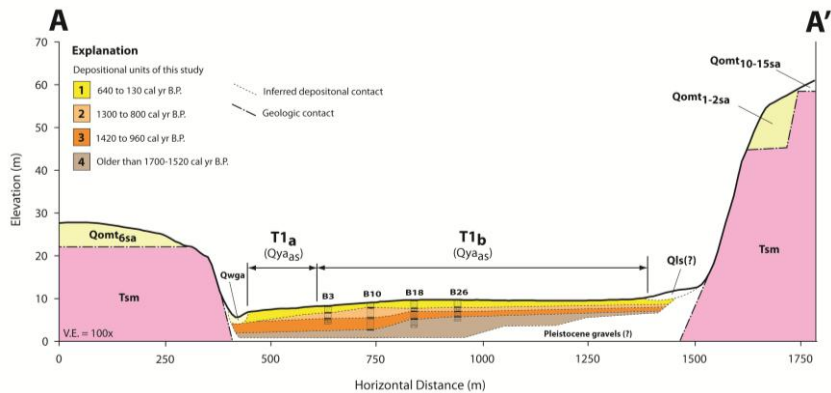
Figure 5.3. West-East geologic cross-section from Tan (1999) modified to show valley fill stratigraphic details as it thickens to the west along transect 4—4'. Queried Pleistocene gravels are based on the composite valley cross-section for San Mateo Creek developed by Waters (1996).

When we superimpose our depositional units on the late Holocene part of the climate change model of Mayewski et al. (2004) there is good agreement with identified rapid global change events (Figure 5.4) of the long Holocene dry period (Unit 4), wet periods from about 1200 to 1000 B.P. (Units 2 and 3) and from about 600 to 200 B.P. (Unit 1) which is at the time of the Little Ice Age. Similar stratigraphic and geomorphic trends in depositional cycles and soil development representing landscape response to rapid climate change have been observed on Santa Catalina Island for the same periods of rapid global climate change (McDonald and Bullard 2007, 2008a, 2008b) suggesting that systems on Santa Catalina Island and at Camp Pendleton are responding in parallel to the same driving forces.
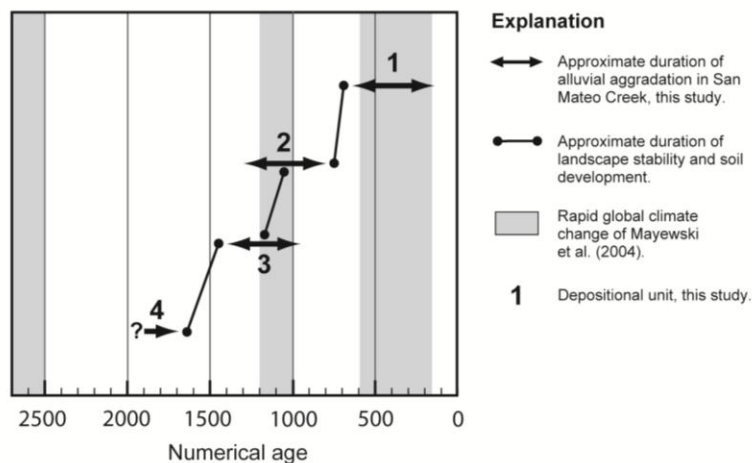
Figure 5.4. Summary diagram showing depositional units, separated by brief periods of landscape stability and soil development, superimposed on global climate change events.

Importance to ARO: The research demonstrates the usefulness of an applied, integrated approach using geologic and geomorphic principles to develop a three-dimensional model to assess the potential for buried archaeological site. The model provides the cultural resource manager a means to assess the potential for buried cultural resources, identify areas of higher potential, design treatment plans, and effectively allocate fiscal resources.

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